Computers

Going to digital extremes

Faster than a speeding gluon, more powerful than a nuclear blast, able to crunch data in colossal bursts? It's the ultimate laptop, envisioned by Seth Lloyd of the Massachusetts Institute of Technology, and it stretches the laws of physics to their limits.

"Computers are physical systems," Lloyd contends. "The laws of physics dictate what they can and cannot do." Lloyd invokes a combination of relativity theory, quantum mechanics, and the laws of thermodynamics to elucidate these outer limits. He describes the result—his hypothetical ultracomputer—in the Aug. 31 NATURE.

For the last 4 decades, steady improvements in manufacturing technology have allowed circuitry to be packed ever more tightly onto silicon chips, doubling computer power every 18 months or so. Lloyd decided to find out what the fundamental constants of nature—the speed of light, Planck's constant, and the gravitational constant—have to say about how far miniaturization can proceed.

Lloyd assumed that his ultimate digital computer would be roughly the size of a conventional laptop, weighing about 1 kilogram and occupying 1 liter of space. Its speed depends on how much energy is available to run it. The fastest design, which is particularly impractical, is one that converts the computer's mass entirely to energy as it makes its first and only run. Quantum mechanics and the uncertainty principle determine how that energy is used by chip components to flip rapidly between two states, representing bits of information. Lloyd estimates that his ultimate laptop would perform at a blazing 10^{51} operations per second. In comparison, today's state-of-the-art computer chips lumber along at a sedate 10^{13} operations per second.

The upper limit on a computer's speed would apply whether the technology involves vacuum tubes, transistors, electrons, quarks and gluons, or something even more exotic, Lloyd remarks.

Another major consideration is memory. "The amount of information that a physical system can store and process is related to the number of distinct physical states that are accessible to the system," Lloyd says. A physical quantity known as entropy, which measures a system's degree of disorder, quantifies this relationship. A high entropy means a large number of different states are available for storing information. Obtaining the maximum entropy requires converting mass to energy in order to create an information-packed memory, which would have the characteristics of a desktop thermonuclear explosion. Lloyd estimates that the resulting memory capacity would amount to 10^{31} bits. Current laptops store 10^{10} bits.

Because the computer's mass can be consumed only once, there'd be a trade-off between speed and memory.

Shrinking a 1-kg computer offers additional benefits. It would take less time for signals to travel from one side of the computer to the other, for example. Lloyd theorizes that compressing the laptop to a tiny fraction of the size of a proton would force its collapse into a miniature black hole. Current theories suggest that this ultradense object could store and process information at incredibly high rates—and, coincidentally, the time required to communicate across the computer would equal the time needed to flip a bit from one state to another.

Lloyd concedes, "There is no guarantee that these limits will ever be attained, no matter how ingenious computer designers become." Even quantum computers, which already operate at computational limits set by physics (SN: 8/26/00, p. 132), are much slower and process much less information than Lloyd's ultimate laptop because their energy is locked up largely in mass.

Thermonuclear explosions show that it's possible to unlock this energy, Lloyd says. "But controlling such an 'unlocked' system is another question," he notes. That's something for engineers and computer designers to ponder, now that they have a better idea of what opportunities might lie ahead. —I.P.

Robots making robots, with some help

To remind themselves how much better their final products could be, robot designers need only look in the mirror. Yet the exquisite biological machines they'll see there emerge from a blind self-replication process, called evolution, and not from a deliberate design effort. In the latter, an engineer devises a robot for welding metal or baking cookies, for instance.

Betting what works for life may also work for artificial life, researchers in Massachusetts have demonstrated the first robotic system that designs and builds robotic offspring from scratch with minimal human intervention.

"The idea that a robotic system can make another robot is not self-reproduction, but it's a step along the way," says Jordan Pollack of Brandeis University in Waltham, Mass. He and Hod Lipson, also of Brandeis, describe their automated robot maker in the Aug. 31 NATURE.

Lipson and Pollack/NATURE

A computer-constructed robot, named Arrow, creeps along a sandy surface.

Last year, Pollack and another colleague set a computer to designing simple structures by a hit-or-miss process that mimics evolution (SN: 9/4/99, p. 156). After many generations, the researchers used Lego blocks to build the computer's designs.

The new project goes a step farther. As before, a computer uses the evolutionary approach to invent moving robots whose ability to travel in a straight line determines their fitness to survive. Now, however, the computer's designs go directly into a fabrication machine that fleshes them out in plastic, leaving only a few accessory tasks to humans: plugging in motors and microchips. —P.W.

Resistance leaps as magnetism mounts

To makers of computer disk drives, the fainter the magnetic field a sensor can detect, the better. If data-reading heads can detect tinier data bits, which have weaker fields, manufacturers can cram more data into less disk space (SN: 4/3/99, p. 223).

Today, commercial read heads are made of layers of magnetic metals stacked into sandwich structures whose electrical resistance changes in response to a varying magnetic field. These so-called giant magnetoresistance heads change their resistance at room temperature by about 5 percent in the presence of a magnetic bit of data, says Stuart A. Solin of NEC Research Institute in Princeton, N.J.

In the Sept. 1 SCIENCE, he and his colleagues unveil a new type of magnetoresistive device about the size of a pinhead. More like a traffic rotary for electrons than a sandwich, it could raise commercially useful magnetoresistance to new heights.

In more recent, unpublished experiments, "we've already obtained over 2,000 percent [resistance change] at magnetic fields relevant to read heads," Solin told SCIENCE NEWS. At high magnetic fields, the researchers have measured resistance change of up to 1 million percent.

Solin and his colleagues have coined a new phrase to describe their invention's behavior: "extraordinary magnetoresistance." To make a device demonstrating the effect, the researchers first deposit a ring of indium-antimonide, about a micrometer thick, onto a gallium-arsenide plate. Then, they fill its center with gold.

In the absence of a magnetic field, current passes handily through the gold, so the resistance is tiny. However, a magnetic field exerts a perpendicular force on moving electrons. As the researchers raise the magnetic field, this deflection forces more current into the indium-antimonide, where resistance is high. —P.W.